Pesticide-free management of weed on golf courses: Current situation and future challenges, European Journal of Turfgrass Science 45(2/14)

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in any study by any treatment (data not shown).

Objective 2: On the bermudagrass putting green, the highest infiltration rate was found on plots treated with Primer Select (~12 cm hr^{-1}) compared to ~6 cm hr-1 on the nontreated plots or plots treated with Hydretain and Cascade Plus (table 2). Localized dry spot was highest (~18%) for nontreated, ~11% for the humectant and <3% for the wetting agent treatments. Fairy ring intensity was lowest (42-43%) for humectant and nontreated and highest (>55%) after treatment with wetting agents. Addition of the fungicide flutolanil to Primer Select did not reduce fairy ring intensity. Soil moisture values were highest for treatments receiving Primer Select (~19%) than in treatments receiving Cascade Plus or Hydretain and the untreated control. Water droplet penetration was quickest (~1.2 sec) after application of wetting agent followed by humectant (3.2 sec) and >5 sec for nontreated.

Objective 3: Treatments did not influence soil volumetric water content of a non-irrigated bermudagrass sports pitch on a native soil (data not shown).

Objective 4: Volumetric water content was higher after addition of Cascade Plus (>20%) but was not influenced by Hydretain (table 3). Soil water content was not influenced by the relative humidity of the surrounding air.

Conclusion

Overall, adding humectant did not consistently increase soil moisture retention or improve turf quality. Wetting agents lowered LDS occurrence and mitigated fairy ring symptoms. Both wetting agents increased soil volumetric water content and decreased LDS, while Primer Select also increased soil water infiltration rate. Previous reports indicate excessive rates of moisture absorbers are necessary for soil moisture retention benefit, often leading to undesirable surface heaving/unevenness (PAEBENS et al., 2010).

	Volumetric Soil Moisture Content (%)							
	Irrigation Regimes							
	Light and Frequent				Deep and Infrequent			
Treatment	14[1]	21	28	35	14	21	28	35
Nontreated	11.7b[2]	8.6a	9.3a	27.5a	9.6a	6.0a	8.8a	9.8a
Humectant	10.3b	7.4a	8.4a	10.0b	9.9a	6.3a	8.3a	9.0a
Cascade Plus[3]	30.8a	7.0a	8.5a	10.0b	8.2a	5.9a	8.4a	10.1a

1 Days after treatment.
2 Within columns means followed by the same letter are not significantly different according to Fisher's LSD (α=0.05) test.
3 Following product label recommendations, a second application was made 7 days after initial treatment.

Tab. 1: Volumetric soil moisture percentage for treatment, various days after treatment, and two irrigation regimes on a 'L-93' creeping bentgrass research putting green.

Treatment	Infiltration Rate	VWC	WDPT	LDS	Fairy Ring Intensity
	cm hr^{-1}	%	sec	%	%
Nontreated	5.3c[1]	10.6b	5.1a	17.5ab	42.7b
Humectant	5.9c	10.1b	3.2b	11.4b	42.1b
Cascade Plus[2]	6.5c	12.3b	1.4c	2.5c	77.3a
Primer + flutolanil[3]	8.8b	18.2a	1.2c	2.2c	58.0ab
Primer Select	11.7a	19.8a	1.0c	2.8c	58.0ab

1 Within columns means followed by the same letter are not significantly different according to Fisher's LSD (α=0.05) test.
2 As per product label recommendations, a sequential application was made 7 days after initial treatment.
3 Flutolanil was applied 24 hrs after the Primer application and mowing was avoided for 24 hours following application.

Tab. 2: Infiltration rate, volumetric soil moisture content (VWC), time for water droplet penetration (WDPT), localized dry spots (LDS) occurrence, and fairy ring intensity as affected by a humectant, two wetting agents and a wetting agent plus fungicide on a 'TifEagle' bermudagrass research putting green.

Treatment	Volumetric Water Content (%)[1]
Cascade Plus	20.2a[2]
Humectant	18.5b
Tap water	18.2b
Deionized Water	16.9c

1 No main effect of relative humidity level occurred, thus, means represent volumetric water content across both levels of humidity.
2 Values in columns followed by the same letter are not significantly different according to Fisher's LSD (α=0.05) test.

Tab. 3: Volumetric water content by treatment for a humectant, a soil wetting agent and different sources of water on a loamy native soil under low (40%) or high (80%) relative humidity conditions for 7 days.

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Pesticide-free management of weeds on golf courses: Current situation and future challenges

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Introduction

Environmental concerns about the use of land for golf courses have grown over the past fifty years. Specific issues include the amount of water, pesticides and fertilizers used for golf course management. These issues have led to research/knowledge collection cases on more environmentally sound practices in turf grass management (James et al., 2012)

In Denmark, the risk of pesticide contamination of groundwater/drinking water reservoirs have resulted in several restrictions on the use of pesticides in urban areas including golf courses. A voluntary agreement between the Minister of Environment and the Danish Golf Federation was signed in 2005. The goal in the agreement was a 75 % reduction in pesticide use on Danish golf courses over a 3 year period. In order to fulfil this agreement, the need for alternative control methods increased substantially (Kristoffersen et al., 2004). From 2005 to 2008 the pesticide reduction was only 37 % and in 2013 legislation was agreed and a ceiling was set on how much pesticides could be used on the different golf course elements.

Playing quality and herbicide use on fairways

There are requirements regarding playing quality on the fairways. It is primarily desirable that the fairway grass has a high shoot density, which can carry the ball. In addition, the fairway should be smooth, uniform and relatively firm, so the ball can roll smoothly after impact. Finally, the fairway should have an attractive appearance, which is equal to a smooth and lush grass cover and no flowering weeds that might interfere with the game (Jensen, 2012; Jensen and Jensen, 2012).

Fairways make up the largest area of the golf course and are generally cut short which favours weeds like *Bellis perennis, Plantago major, Poa annua, Taraxacum sp.* and *Trifolium repens* (Jensen et al., 2012). A variety of factors can affect the occurrence of weeds in turf – both fundamental factors such as soil and climate, and issues relating to turf management (Miltner et al., 2005). Weeds can impair on course quality and therefore should be controlled. For years pesticides have been the major method of weed control.

Because of the requirements for a high playing quality on fairways and because of the large area they constitute, fairways receive a significant part of the golf course's overall management efforts, including pesticides. In the Danish Golf Federations yearly green accounts for Danish golf courses, fairways contribute approximately 75 % of the total pesticide consumption. Consumption is primarily due to herbicides (DGU, 2006, 2011).

Weed control on fairways has in decades been almost exclusively based on the use of selective herbicides. There has been very little focus on the development of culture technical methods, such as a good lawn maintenance that can promote grass growth conditions as well as the grass competitiveness against weeds.

Now that pesticide legislation on golf courses has come into force, there is an increased need to develop and improve methods for pesticide-free weed control on fairways.

Overview of strategies for pesticide-free weeds control

Pesticide-free weed control in a lawn includes different strategies. The first and most important strategy is to promote grass plant density which makes the lawn more competitive against invasion of new weeds. One important aspect is to increase fertilization (Jackman and Mouat, 1972). Fertilizer promotes grass growth, and several studies have found that an increased application of fertilizer can reduce the amount of weeds in the lawn (Kopp and Guillard, 2002). When the intention is to fight weed with fertilizer it is important to find an optimal balance between increasing the competitive ability of the established turf and the increased risk of nutrient runoff and leaching.

Other pesticide-free strategies are mechanical, thermal and cultural practices that stress, harm or kill weeds (Andersen, 2000). Mechanical and thermal weed control methods available mainly for combatting weed on pavements but different methods such as grooming, harrowing etc. have been tried on turf because these methods might damage the weeds (Kristoffersen et al., 2004; Rask and Kristoffersen, 2007). A common feature of non-chemical weed control methods is that repeated treatments are required in order to achieve efficient control. In contrast, using chemicals for weed management only requires one or two treatments each year (Popay et al., 1992; Augustin et al., 2001; Reichel, 2003). Non-chemical treatments mainly affect the aboveground plant parts, whereas systemic herbicides kill the entire plant (Popay et al., 1992). Vertical cutting, tine harrowing and topdressing are maintenance methods that can enhance grass growth but the effect on weed occurrence have only been tested on a small scale and not in relation to individual weed species (Fischer and Larsen, 2002; Larsen and Fischer, 2005). In general the methods mentioned are all non-selective in relation to weed species and they can adversely affect the turf too.

A third strategy to control weeds is the prevention of seed dispersal. A fourth strategy includes the use of biological control agents such as special types of compost or bacterial or fungal substances.

Mechanical weed control

The most common management practices on golf fairways in Demark are mowing and fertilization. Less frequently fairways are vertical cut, harrowed or aerated, and on a few golf courses fairways are top-dressed and over seeded.

In the past, management practices such as vertical cutting, harrowing, aeration or top-dressing were mainly regarded as methods to regulate growth and control thatch. However, a Danish research project challenged these management methods in relation to their effect on weed control (Fisher and Larsen, 2002; Larsen and Fischer, 2005).

The mechanical methods believed to have the greatest impact on weed control are those that affect the lawn surface. Vertical cutting is designed to promote growth conditions of the grass by removing dead plant material, but also to stress the weeds by removing a part of the leaves or the inflorescences. The same effect can be achieved by using a harrow, but thatch and inflorescence are not removed to the same extent. Larsen and Fischer (2005) demonstrated that spring-tine harrowing 4-5 times a year significantly decreased weed cover and significantly increased grass cover at Furesø and Viborg golf course. The decrease in weed cover was between 1,2 % and 2,1 % and the increase in grass cover between 1,1 % and 2,6 %. When choosing the treatment intensity it is important to know the optimal balance where weeds are inhibited without disturbing grass growth.

The experiments by FISHER and LARSEN (2002) investigated the optimal treatment frequency and treatment combination. Vertical cutting, various types of harrowing, fertilizer amount, top dressing and other management factors were evaluated in various combinations. These trials demonstrated that the effects on weed occurrence were mostly small and the overall reduction in weeds on football pitches and golf course fairways was not significant.

The poor efficacy of mechanical weed control methods in FISHER and LARSEN (2002)'s experiments calls for a more differentiated approach towards pesticide-free weed control. We believe that the way forward is to refine methods that can be used on small areas depending on the target weed species. In order to get ideas for the optimal weed control strategy for the individual species we need to evaluate the practical experiences on golf courses. In the following experiences from practical trials initiated by greenkeepers are presented and discussed in relation to using them in a differentiated pesticide-free weed control approach.

Weed burning

In Denmark a number of experiments on burning weeds on pavements have been carried out (Kristoffersen et al., 2008; Rask et al., 2012). Sensitive weed species responded to a dose between 10 and 150 kg gas per hectare, and 95 % control of sensitive species such as *Chenopodium album* was obtained. Plants with a protected apical meristem such as the grasses needed a higher dose in order to be controlled (Ascard, 1995, 1998). Therefore burning might be effective in removing some problematic weed species from a smaller lawn area without eliminating the grass plants. Some injury on the leaves can be expected, but the grass will be able to overcome these injuries because the growth meristem is protected and close to the ground (RASK and KRISTOFFERSEN, 2007)

In a small burning experiment at the driving range at Furesø golf course (Copenhagen) in 2010-2011 (burning 2 times in fall and 2 times in spring) *Bellis perennis* responded to a gas dose of 80 kg per ha (Table 1). Two weed species, *Taraxacum sp.* and *Trifolium repens*, did not respond to flaming. After burning the turf showed injuries, between 5-40 % – depending on the gas dose but recovered after 2-4 weeks. For *Cerastium fontanun* there was an increase from fall to the next spring but burning provided control compared to the non-treated.

This small experiment indicate that some weed species might be sensible to a burning treatment and that weed control using a weed burner might be a solution in small restricted turf areas. The next step is to perform an experiment for a longer period on a larger scale for multiple weed species.

Stripping off old and weedy turf followed by resowing

Some weed species have a very superficial root growth whereas others have a tap root. Stripping off turf followed by resowing might be a method to reduce the number of superficially rooted weed species and the seed bank of certain weeds in the soil. At the same time, the botanical composition can be changed in favour of more competitive or durable grass species/varieties.

Stripping off the turf has been used earlier when renovating greens (Mortensen et al., 2005). One of the advantages is that stripping off the top 2-3 cm removes most of the seed bank of annual meadow-grass (*Poa annua*) which can be more than 150000 seeds per m^2 (Lush, 1988). A Norwegian study investigating various methods for renovation of greens after winter-kill documented that stripping off the turf followed by resowing of a mixture of red fescue (*Festuca rubra*) and brown top bent (*Agrostis capillaris*) resulted in a botanical composition of 99 % fescue/bent and only 1 % annual meadow-grass as opposed to 48 % fescue/bent and 52 % annual meadow-grass in the control treatment where the seed mixture was drilled directly without stripping (Kvalbein, 2009).

The greenkeeper at Furesø Golf Course (Copenhagen) tried stripping plus resowing as a means to reduce weed occurrence and change the botanical composition on fairway in favour of red fescue (*Festuca rubra*). His experience was that stripping off the old turf removed *Cerastium fontanum* as these weeds did not appear the year after. However weed species with taproots, such as *Taraxacum sp.* and *Plantago sp.* were not removed. They reappeared quickly in the new turf.

Stripping is very expensive. The estimate from Furesø GC was that it took 4-5 hours to strip 800 m^2. Therefore stripping is not a solution on large areas. However it might be a solution for weed management in small areas depending on the type of weed.

Grazing

For many years grazing has been used for landscape management (Hadjigeorgiou et al., 2005). Some animal species are very effective in grazing/eating weeds (Popay and Roger, 1996). A number of golf courses in Denmark and Sweden are now using animals for weed control.

Species	Change in control treatment (%)	Change in flaming treatment (%)
Taraxacum sp.	-0,31	-0,43
Trifolium repens	-4,25	-4,07
Bellis perennis	-0,79	-2,07
Medicago sativa	0,85	0
Cerastium fontanum	2,61	1,10

Tab. 1: Change in per cent coverage of weeds from fall 2010 to spring 2011 in a burning experiment at Furesø GC, Copenhagen (80 kg gas per ha).

On Hørsholm Golf Course north of Copenhagen grazing was originally established on a part of the course where the sheep had access to all of the golf course elements (greens, tees, fairway and rough). Before grazing was initiated the establishment of clover (*Trifolium repens*), poplar (*Populus sp.*) and the black-list species giant hogweed (*Heracleum mantegazzianum*) was a major problem. The introduction of sheep on the golf course helped to alleviate these problems. This effect on giant hogweed was also observed at Smørum Golf Course (Copenhagen) where the animal ate the seedlings before the inflorescences were produced. At Hornbæk Golf Course (North Zealand) three years of grazing have demonstrated that sheep were efficient in preventing willows (*Salix sp.*) and birches (*Betula sp.*) from getting establishment (Jensen and Edman, 2011).

Besides controlling weeds, grazing will also change the character of the rough. By eating many of the large and competitive grass species, sheep create an open rough with fine grasses and a better playing quality because the players are able to find the golf ball.

However there was one main problem with the grazing regime at Hørsholm. The sheep were lying on the greens at night and their urine caused scorched spots on the greens. That was not acceptable and today the greenkeepers keep the sheep in mobile enclosures mainly in the rough areas.

Specific equipment for weed control/management

Some greenkeepers have tried to develop or modify mechanical equipment to achieve better control of target weed species.

At Värpinge Golf Course Sweden, a modified vertical cutting aggregate for a Toro 5610 was tested to control dandelions (*Taraxacum sp.*). Blades were mounted at a distance of 2.5 cm. The blades did not go into the topsoil/ but operated at a height approximately 1 cm above ground and disrupted the leaves of the dandelions. This treatment did not remove the dandelion but the plants became smaller and the negative effect on the playing quality was diminished. This example shows that investigations into weed control on fairways should not only focus on how to kill the weeds, but also on how to manage them in order to minimise the negative effect on playing quality.

Overseeding and topdressing

Overseeding has not been a common maintenance procedure on Danish golf fairways. However, the introduction of new plants with higher shoot density will usually result in less space for the establishment and growth of weeds (Morris, 2004; McCarthy, 2009). Overseeding might therefore have a long term effect on weed occurrence.

The experiments by Fisher and Larsen in 1999-2001 showed conflicting results of overseeding plus topdressing depending on seeding rate, seeding time and soil fertility levels (Larsen and Fischer 2005). A clear positive effect on weed occurrence after two years was seen at Viborg GC (Jutland), and this effect was still visible ten years later (Nyholt, 2010).

At the moment a research project is ongoing in Denmark and Norway investigating the effect of different overseeding procedures on weed occurrence.

Earthworm castings and weed establishment

A major problem on many golf courses is the creation of earthworm casts on fairways, tees and sometimes even on greens (Collins et al., 1995; Williamson, 2004; Potter et al., 2013). Especially in autumn, there may be many worm casts. These casts are smeared by the machines used for maintenance and they become perfect niches for weed establishment. In particular annual meadow grass (*Poa annua*) will be promoted by these casts due to its ability to germinate almost all year around.

The head greenkeeper at Furesø Golf Course performed a number of small experiments in order to find a method for reducing earthworm casts on fairways with clay soils. He found applications of sand mixed with an acid fertilizer reduced the pH and moisture in the top soil. His experience was that not only the number, but also the structure of the casts changed, thus allowing less annual meadow grass and other weeds to germinate. His findings are in agreement with GUILD (2008) and POTTER et al. (2013) showing that the upward and downward movements of earthworms in the soil are influenced by soil moisture and soil temperature, and that earthworms are sensitive to acidic soil conditions.

Future directions

The future calls for a reduction in herbicide use in turf due to legislation and volunteer agreements. Danish experiments and practical experiences on pesticide-free control demonstrated that so far we have no universal or selective methods that can effectively eliminate weeds on golf courses.

Weed species respond differentially to mechanical treatments and the timing and frequency of specific mechanical treatments also have a strong impact. Therefore the approach regarding mechanical weed control needs to be changed. More knowledge of the individual weeds' morphology, physiology and demography under turf conditions is needed to find effective mechanical weed control methods. Understanding the various growth stages where the weed species may be most vulnerable to mechanical damage is particularly important (Nkurunziza et al., 2011).

The indications that burning might have an impact on some weed species without harming the grass plants and that stripping can remove the seed bank and eliminate weed species with a superficial root system should encourage a more profound investigation of these methods in relation to weed control. These methods might be reasonable to use in small areas with severe weed problems. We must also to a larger extent establish thresholds for the individual species in order to decide when a specific treatment is justified to improve the functional quality of the turf.

From an economic perspective, there is no doubt that pesticide free management is more time consuming and expensive than chemical control, and this is likely to influence the willingness of turf managers to choose non-pesticide options in a time with increasing economic pressure on many golf clubs. Furthermore, if aspects such as fossil fuel consumption and CO_2 emissions are included, it remains to be documented if managing turf weeds totally without herbicides is more economically and environmentally sustainable than management with a minimum input of herbicides according to IPM principles. However, by targeting non-chemical methods to the biology and weaknesses of the individual weed species under turf conditions, it should be possible to reduce the golf courses' dependence on herbicides for weed control.

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